BROADENING THE COMPARISON OF GASOLINE TAXES AND CAFE STANDARDS: DISCOUNTING AND VALUATIONS OF VEHICLE SAFETY CHANGES

by

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DISCLAIMER

ABSTRACT

A number of policies have been proposed to raise the fuel economy profile of the domestic privately owned vehicle fleet, including fuel. economy standards and gasoline taxes. This research estimates two values which are essential inputs for a comprehensive benefit-cost assessment of these policies, the discount rate and the value of a statistical life. Using an original data set describing the vehicle holdings of a randomly chosen selection of households, an hedonic model incorporating life cycle vehicle costs and safety outcomes is estimated. The estimated model generates two important measures embodied in household automobile stocks, namely, the implicit discount rate and the value of a statistical life. The revealed mean equilibrium real discount rate of 15.7 percent indicates that consumer discounting behavior differs from what economists typically consider efficient choices in that the implicit rate exceeds market rates of return. Policy alternatives which influence individual behavior through vehicle operating costs may be less effective due to high individual discount rates. Because fuel economy improvements may come at the expense of vehicle safety, a comprehensive assessment of fuel economy policies must value any induced safety changes. The mean implicit value of a statistical life estimated from household automobile holdings of $2.48 million (in $1988) is consistent with but somewhat lower than values estimated in the labor

market. Valuations of a statistical life year are also presented.

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I. Introduction and Motivation

The growing awareness of the environmental and economic costs of inefficient energy use and the strategic security of energy supplies have driven the United States to examine policy options to curb growth in domestic energy consumption. The 1992 presidential election and the beginning of the new administration have focused even more attention on domestic energy consumption. In 1993, the Congress considered the President's proposed broad-based energy tax, but ultimately settled on additional gasoline excises. Automotive fuel economy will in all likelihood be addressed by the new administration after being a most heated issue in the presidential campaign.

Improved energy efficiency in the transportation sector lies at the heart of reducing domestic oil consumption as the transportation sector accounts for approximately two-thirds of petroleum use. By far, the largest fuel consumption share in the transportation sector is light duty vehicles, composed of gasoline and diesel fuel-powered private automobiles and light trucks. These vehicles account for nearly 60 percent of transportation sector fuel use. In all, gasoline-powered privately owned vehicles consume 40 percent of total domestic petroleum used and approximately nine percent of gross domestic energy consumed from nonrenewable sources (USDOE 1991).

Environmental concerns, also point to gasoline consumption as a significant source of health and environment-threatening pollutants and as a large source of greenhouse gases. Pollutants from the combustion of motor fuels may be responsible for as many as 50,000 to 120,000 annual deaths according to the American Lung Association (DeLuchi 1990). At current emissions levels, the American automobile fleet contributes a substantial portion of global emissions of greenhouse gases. Renewed emphasis on environmental policies now heard from Washington indicates the likely linkage between energy conservation policy and environmental management. Automotive fuel consumption is one such area where energy and environmental goals may be pursued in tandem.

Two particular policies are most often raised as instruments addressing gasoline consumption, gasoline taxes and the corporate average fuel economy (CAFE) standards. These policy options follow quite disparate approaches, the former operating through gasoline prices while the latter imposes an efficiency standard on all new vehicles. A number of researchers have examined the relative economic efficiency of the two proposals. Crandall (1992) most recently summarized studies of the efficiency consequences of the CAFE standards. He concluded that the fuel economy standards approach is substantially more costly--up to seven to ten times greater--for achieving an equivalent reduction in gasoline consumption.

These conclusions evaluate one important aspect of the policies. A comprehensive assessment in a benefit-cost context must look more broadly at the consequences of each approach. Because the two policies operate through very different incentive mechanisms, substantially different consequences for consumer behavior could arise.

This study develops empirical data which may be incorporated in a broader evaluation of alternative methods to reduce domestic demand. The empirical model developed in this research incorporates data on households' automobile stocks, the attributes of their automobiles, and the demographic characteristics of those households. These measures are used to generate empirical data on two specific topics which should be incorporated in a comprehensive comparison of gasoline consumption reduction policies, consumers' tradeoffs between the cost of car purchase and life cycle considerations revealed by their implicit discounting behavior and the implicit value of a statistical life revealed in their household automobile holdings.

The remainder of this section reviews the policies which have been discussed as mechanisms for reducing domestic gasoline consumption. In section II, the economic model is developed. Section III presents the empirical results and section IV discusses their consequences for policy.

A. Policies Designed to Curb Gasoline Consumption

Net automotive gasoline consumption is determined by two interrelated factors, the fuel economy performance of a vehicle and the number of miles which that vehicle is driven. These two factors are related by a price, the price of driving a vehicle a given distance, a function of both the price of gasoline and the fuel economy of the vehicle (ignoring other considerations such as depreciation, insurance and allocated maintenance costs). The higher the fuel economy, the lower the price to operate the vehicle per given distance. A simple demand relationship suggests that more fuel efficient vehicles will be driven more miles. Similarly, an individual who drives a large amount may be attracted to a more fuel efficient vehicle.

This fundamental interrelationship between fuel economy and miles travelled highlights the two different policy approaches which may be pursued to curb gasoline consumption. Policies may target miles of travel or the fuel economy of the vehicle fleet. Either approach may spill over onto the other, and some policies may directly affect both travel and fuel economy.

The empirical results generated in this research are primarily directed at policies which target fleet fuel economy. Though miles travelled will only occasionally be addressed here, the policies reviewed below for altering the fuel economy profile of the vehicle fleet cannot be thoroughly considered without examining their incentives for driving behavior.

1. The Federal Gasoline Excise Tax

The federal excise tax on gasoline is collected from consumers at the pump for each gallon of gasoline purchased. Though a tax, this approach is a second-best measure because the tax level is not determined by any estimate of social cost. Currently, a federal excise of 14.1 cents is levied on every gallon of gasoline (U.S. DOE 1992). An additional 4.3 cents per gallon will be levied as a result of the Clinton budget bill.

The federal excise is only one tax which affects the price of gasoline. There are state and local excises, state severance taxes, windfall profits taxes, and environmental (Superfund) taxes. In all, Viscusi, Magat, Carlin, and Dreyfus (1993) estimated that the national average unit gasoline tax was approximately 23 cents per gallon in 1986, accounting for 25 percent of the retail price. They further estimated that the optimal additional tax to restore full social cost pricing was approximately 28 cents in 1986, but could be as high as $1.07 in the upper bound.[1]

[1] These optimal tax estimates incorporate air pollution externalities only. Gasoline-related pollution at points other than the tailpipe (e.g. drilling, refining and disposal sites) was not incorporated nor were the potential burdens of the gasoline share of global warming nor energy security externalities.

Gasoline taxes affect fuel consumption through two distinct routes. The immediate effect is through the cost of operating a vehicle for each mile travelled. Higher gasoline taxes discourage driving by raising the unit price. Individual trips may be combined or eliminated. More drivers may switch to carpools, mass transit, or other alternatives. In the longer term, transit system development may change due to the changes in driving demand patterns. Some of these results will be immediate while others will be adopted over time.

Fleet fuel economy is the second route through which gasoline taxes alter fuel consumption. Taxes raise life cycle vehicle operating costs which may encourage consumers to purchase more fuel efficient vehicles. Changes in fleet fuel economy performance will only occur over time as newer, more fuel efficient vehicles are introduced and older, less efficient vehicles retired from service. Owning a fuel efficient vehicle in turn, lowers the price of driving. Enhanced fuel efficiency may lead to a greater gasoline consumption "rebound." Unlike the direct effect of the increase in the cost of driving, fleet fuel economy changes--and any associated fuel consumption rebound--will only occur over time as drivers replace their older, less fuel efficient vehicles with newer, more fuel efficient vehicles. Higher costs of operation may, however, accelerate turn over in the vehicle fleet.

Much as the gasoline tax alters gasoline consumption through two routes, miles driven and fleet fuel economy, the safety consequences of the tax occur through two routes. As drivers travel fewer miles in their cars either by driving less or switching transit modes, the opportunities for accident and injury are reduced. But if as a result of the long-run consequences of the higher price, consumers purchase more fuel efficient vehicles which are less safe, the tax may indirectly increase the rate and/or adverse consequences of accidents. The relationship between higher fuel efficiency and decreased safety is well established (see for example Evans 1984 and Crandall & Graham 1989). Safety consequences should be incorporated in a comprehensive evaluation of these policies.

2. **The Corporate Average Fuel Economy Standard**

The corporate average fuel economy standards (CAFE)' set an average fleet fuel economy standard which must be met by each automobile manufacturer, currently at 27.5 miles per gallon (mpg) for passenger cars and 20.5 mpg for light trucks.[3] The fleet standard must be met separately by both the manufacturer's domestic and import fleets. Mileage credits for

[2]Established in the Motor Vehicle Information and Cost Savings Act, 15 U.S.C. 1901, amended by the Energy Policy and Conservation Act of 1975 and The Alternative Motor Fuels Act of 1988.

[3]Calculated as the harmonic average of each vehicle in a manufacturer's fleet. For General Motors (GM), for example, the harmonic average of fuel economy of all domestic passenger cars, including all Buicks, Oldsmobiles, Chevrolets, Pontiacs, and Cadillacs must meet 27.5 mpg to achieve compliance. The harmonic average of all of GM's imported passenger cars must also meet the 27.5 mpg standard.

exceeding the standard may be carried forward or back for three years. Failure to meet the fleet performance standard results in a fine of five dollars for every one-tenth of a mile per gallon below the standard for every auto in the noncomplying manufacturer's fleet.

Since 1978, the first year in which manufacturers were required to meet CAFE standards, fleet fuel economy has grown 40 percent from approximately 20 mpg to over 28 mpg in 1991 (USDOT various years). Although the fuel economy achieved by the new car fleet improved substantially, total gasoline consumption fell only 2.5 percent by 1987 as the total number of miles travelled in the U.S. rose from 1.1 trillion to 1.4 trillion by 1988 (USDOT 1990).[4]

Unlike the gasoline tax, fuel economy standards have no direct influence on the cost of driving an existing vehicle. The standards will only alter fleet fuel economy performance over an extended time period. New vehicles would be required to comply with the standard after a phase-in period for vehicle redesign and production retooling, typically assumed to be at least four years. Over time, the fleet would become more

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[4]Several authors have investigated whether improvements in fleet fuel economy were due to imposition of the CAFE standards or other causes. Both Crandall, Gruenspecht, Keeler, & Lave (1986), and Greene (1990) examined improvements in fuel economy of the domestic fleet during the 1970's and 1980's. Their studies suggest that market conditions led to fuel economy improvements during periods of rising gasoline prices, but at other times, only regulatory standards maintained fuel economy improvements. If this pattern of fuel economy changes continues, then current market conditions suggest that additional fuel economy improvements may not be achieved without further market intervention.

efficient at new models are introduced each year and existing vehicles are scrapped.

The CAFE standards create two indirect incentives which could partially offset some of the fuel efficiency gains of the requirements. Because vehicles would be more fuel efficient, they may be driven more miles due to the lower unit cost of driving. This result would be different than a tax-induced change in fleet fuel economy because the higher tax rate would simultaneously *raise* the price of driving while encouraging a more efficient fleet (lowering the cost of driving). In other words, with standards there would be no offsetting increase in the price of gas discouraging rebound driving. A second offsetting incentive could be created if the standards raise new vehicle prices. If new cars are more expensive, then consumers may hold their existing, less fuel efficient vehicles longer.

Unlike the gasoline tax, fuel economy standards have no direct effect on risk. Automobile safety is only altered indirectly over time through changes in fleet fuel performance. As new vehicles are designed to achieve greater fuel economy, safety may suffer. For every mile driven in such a vehicle, the risk of accident and/or the consequences of an accident would be higher. In one analysis of this scenario, Crandall and Graham (1989) estimated that the mortality rate associated with the 1989 vehicle fleet would be from 14 to 27 percent greater than in the absence of the CAFE standards.

3. **Other Policies** to Reduce Gasoline Consumption

The gas guzzler tax[5] imposes a penalty on manufacturers of automobiles that fall below a minimum level of fuel economy, currently set at 22.5 mpg, with the tax rising the further fuel economy falls below 22.5 mpg. In recent model years, vehicles qualifying for the gas guzzler tax included primarily luxury models such as the Mercedes 300 series, the Cadillac Brougham, and the BMW 535i.[6] Total gas guzzler tax receipts in 1991 reached $118.4 million (MVMA 1992).

This approach creates an incentive to improve fuel economy in the least efficient segment of the private vehicle market by raising vehicle price. At a higher price, fewer vehicles in this class should be sold. If however, demand for such luxury vehicles is highly inelastic, then the gas guzzler tax may have little, if any, influence on fleet fuel economy. If on the other hand, buyers shy away from vehicles subject to the gas guzzler tax, then manufacturers will have a strong incentive to address fuel economy of their gas guzzling vehicles. Consumers considering new vehicles in this least efficient market segment may be induced to hold their existing

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[5]26 U.S.C. 4064.

[6]For the 1988 model year, the tax for a Mercedes 300 was 650 dollars, and for the BMW 535i, from 500 to 850 dollars depending upon the transmission type (Ward's Automotive 1988).

vehicles longer if they find the higher prices of gas guzzlers burdensome. Increased risk to consumers could result if more fuel efficient, less safe vehicles are substituted for gas guzzlers.

A policy option which is being discussed in California but not yet implemented is the so-called "feebate" proposal (California Energy Commission 1992, DeCicco, Geller & Morrill 1992). Feebates would impose a schedule of fees and rebates on new car buyers. Those purchasing cars with fuel economy above a designated level would receive a rebate, while buyers of cars with fuel economy below the designated amount would pay an additional fee, much like the gas guzzler tax. The fees (rebates) would be designed to rise as fuel economy fell further below (above) the designated level. The entire system could be implemented as a revenue generating or revenue neutral program. Again, if consumers shift to more efficient, less safe vehicles, increased risk could result.

Bounty programs, also called car crushing, and cash-for-clunkers are designed to reduce domestic gasoline consumption by removing older, less fuel efficient vehicles from the road. Cash-for-clunker programs have already been implemented in a limited fashion where car crushing is being used by manufacturers and utilities as an offset for new emissions (La Ganga 1993).

Bounty programs address only the most fuel inefficient vehicles. If these vehicles would not soon be retired in the absence of such a program, then paying bounties may achieve significant fuel savings. If these vehicles would be scrapped anyway, then the programs may have little if any fuel savings. Typically cash-for-clunker programs designed to save fuel are considered in conjunction with other programs rather than as stand alone proposals.

The safety consequences of such a program are uncertain. If automobiles are eliminated without substitution by a new vehicle, then safety may improve. Just as the name indicates, clunkers may often be inherently unsafe, so substitution with a more fuel efficient vehicle may reduce risk.

Comparisons between any or all of these policy approaches should be made in a comprehensive benefit-cost environment. This research estimates two measures which are important inputs for any such analysis. Knowing the consumers' discount rate is important for understanding how consumers incorporate life cycle risks and life cycle vehicle operating costs into their vehicle holdings. This is especially important for comparing excise taxes with fuel economy standards because standards push car buyers to more efficient vehicles through marketplace controls--which operate over time--while taxes affect fleet fuel economy by creating an immediate incentive based on life cycle costs. The discount rate is a key component for determining whether price incentives can achieve the same marketplace outcomes as standards.

Any of these policy approaches may have safety implications because different segments of the vehicle market, while having different levels of achieved fuel economy, have different safety levels as well. By altering the fuel economy of the fleet, and presumably altering either the size or composition of those vehicles, safety will be affected. Each policy should be evaluated in terms of its safety implications. Incorporating these implications in a benefit-cost environment requires placing some monetary value on safety changes. The most appropriate source for those values are from the vehicle holdings of households, directly reflecting consumer willingness-to-pay for safety as embodied in their vehicles. These two issues are the subject of the following sections.

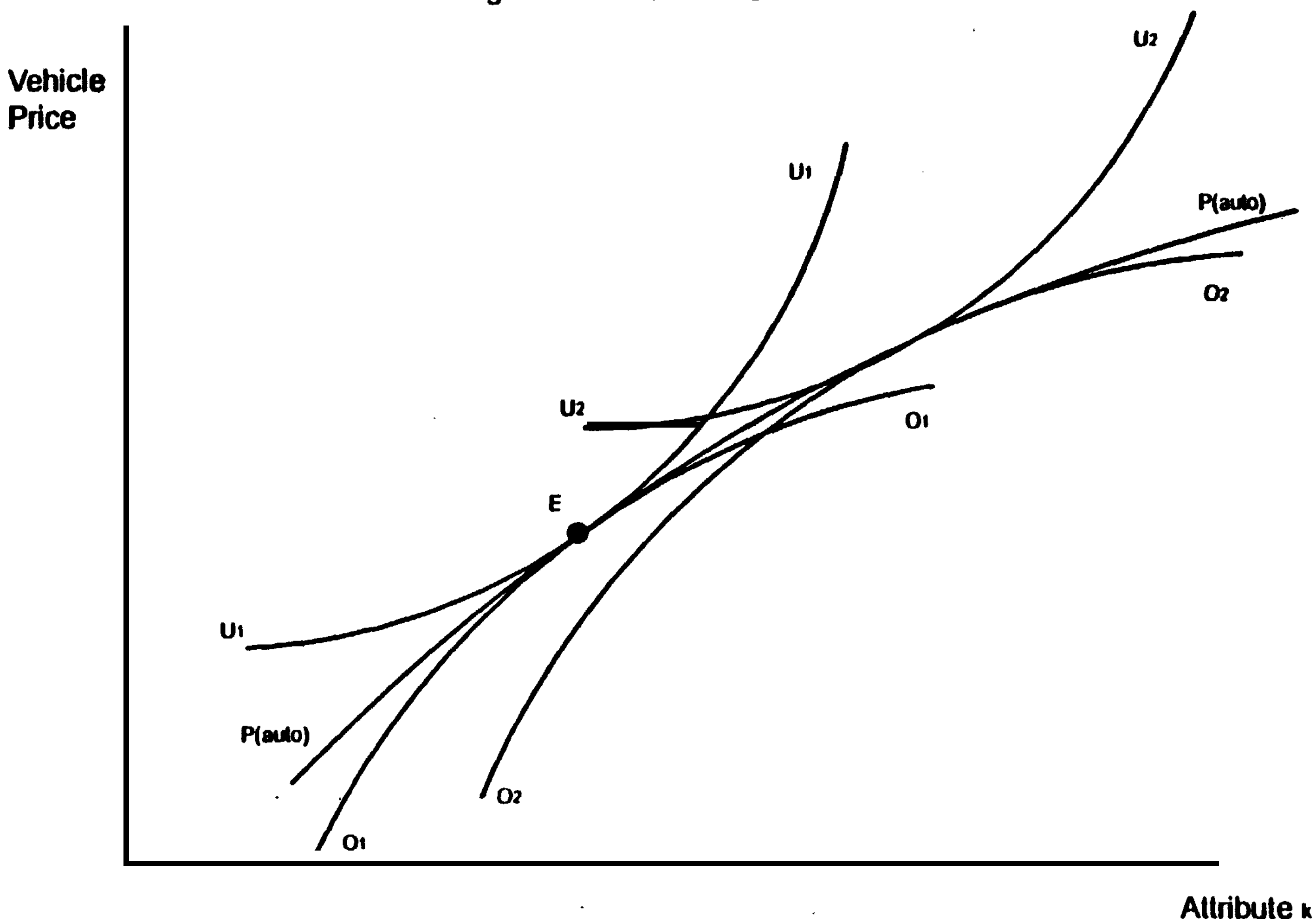
II. An Automobile Attribute-Based Approach to Evaluate Fuel Economy Improvements

In the analysis that follows, an hedonic approach is used to evaluate changes in fuel economy from the programs described above. This approach recognizes that when buying an automobile, a consumer is buying a bundle of underlying attributes all tied together in the vehicle. Individual attributes are valued by the consumer, either explicitly or implicitly, and different vehicle- bundles reflect tradeoffs among the attributes based on these values. Results from this model will be used to estimate the real discount rate and the underlying value of a statistical life reflected in households' holdings of automobiles.

A. *The Hedonic Attribute-Based Approach*

The underlying economic theory of hedonic analysis **was** first formalized by Rosen (1974), though hedonic techniques had been used **as** an empirical method for many years before his work (e.g. Court 1939, Griliches 1961). Following Rosen's approach, the equilibrium vehicle price locus depicted in Figure 1, P(auto), is determined by the simultaneous demand and supply decisions of consumers and producers over the collection of attributes embodied in a vehicle. Consumers' and producers' attribute choices are represented by their placement along the

Figure 1: The Hedonic Price Locus



price locus. Each choice decision represents that individual's or firm's tradeoff between vehicle price and the level of the attribute. In the figure, U, and U_2 represent the preferences of consumers one and two. Similarly, 0, and 0, represent producers' offerings. Consumers choose the amount of each attribute desired along the price locus, receiving compensation for their chosen attribute level in terms of vehicle price or some other attribute. The equilibrium marginal value of an attribute is determined when a consumer and a producer choose the same amount of attribute k along the price locus, as in point E. Using an empirical approach, the implicit marginal values assigned to these attributes at points like E can be revealed, and the rates of trade, or compensation, between attributes identified.

B. *An Empirical Model* Based *on Automobile Attributes*

A differentiated good may be represented by the bundle of characteristics embodied in that good. For an automobile, these characteristics, designated below by each A,, may include such items as the fuel economy of the vehicle, its level of safety, the number of seats, and so on,

$$\text{auto} = (A_1, A_2, A_3 \ldots A_n).$$

In **a** competitive equilibrium, the price of the good is a function of the implicit prices of the bundle of attributes making up the automobile,

$$P_{(\text{auto})} = P(A_1, A_2, A_3 \ldots A_n).$$

This relationship, P(auto), defines the hedonic'price function, the equilibrium locus of vehicle prices resulting from the market interactions of producers and consumers for different bundles of vehicle characteristics.

Once the empirical estimation of the equilibrium hedonic price locus is completed, determination of implicit marginal attribute prices is straight-forward. Each implicit marginal price is simply derived as the partial derivative of the equilibrium hedonic price locus with respect to the attribute of interest, A_k, or

$$p\ (A_k) = \frac{\partial P_{(\text{auto})}}{\partial A_k} = P_{A_k}\ (A_1, A_2, \ldots A_n).$$

This value, the change in automobile price associated with an additional unit of an attribute, reveals consumers' marginal willingness-to-pay for an additional unit of that attribute as embodied in the auto bundle. The same value simultaneously reveals the firm's marginal cost of providing another unit of the attribute.

Similarly, the marginal willingness-to-trade between two different attributes can be determined by appropriately comparing the implicit marginal prices of the two attributes. If the equilibrium hedonic price locus is a linear function, then each marginal implicit price will be constant for any level of the attribute. However, if the locus is nonlinear, then implicit prices will vary with the magnitude of the attribute. The unique preferences of each heterogeneous consumer determine the consumer's unique marginal valuation of an attribute. For example, in Figure 1, if attribute k is vehicle safety, then for consumer two, choosing a very safe car, an additional safety improvement may yield little extra value, but for a less safe vehicle, consumer one may be willing to pay a larger amount for an additional safety increment.

In the empirical estimates that follow, data drawn from household vehicle holdings are used to estimate vehicle price as a function of a collection of attributes, including, vehicle safety, fuel economy, power/acceleration, maintenance rating, durability, size, age, and import/export status. The reduced form of the'estimation equation is

$$P_{(\text{auto})\ i} = \sum_{k} \beta_k A_{ik} + e_i,$$

where the price of auto i is a function of the k vehicle attributes and other unmeasured attributes represented by the error term e.

C. ***Au Hedonic Model-Based Life Cycle Approach***

In several recent papers, Moore and Viscusi demonstrate a method of introducing life cycle measures into an hedonic labor market context (Moore & Viscusi 1988, 1990a, 1990b, Viscusi & Moore 1989). The life cycle measures contain an implicit discount factor which is one output of the model's empirical estimation. Their model explicitly incorporates the observation that each individual has an uncertain number of life years remaining. A related approach will be used in this analysis to determine consumers' discount rates for operating costs given an uncertain remaining vehicle life. Similarly, an analysis is performed to determine the discount rate for safety where the vehicle owner faces an uncertain number of remaining life years.

Data on the age distribution of the vehicle fleet is used to determine each vehicle's expected remaining useful life, T_i. Given the expected vehicle life, the present discounted value of operating costs (PDVOC) can be calculated as the discounted sum of operating costs in each year of the vehicle's remaining life,

$$\text{PDVOC}_i = (1 + e^{-r_1} + e^{-2r_1} + \ldots + e^{-(T_i-1)r_1})\text{OPERATING COST}_i$$

which can be solved to yield,

$$\text{PDVOC}_i = \frac{1 - e^{-r_1 T_i}}{r_1}\text{OPERATING COST}_i$$

where r_1 is the implicit discount rate. The implicit discount rate of any individual will reflect the individual's rate of time preference and any premia for liquidity, risk, and uncertainty. The expected remaining life of the vehicle is determined from historic data on the age distribution of the vehicle fleet.

A similar approach is used to weight the present discounted value of the vehicle owner's additional life years by the mortality risk of each vehicle. Using estimates from life expectancy tables incorporating the age, gender, and race of vehicle owners, the expected remaining life of each vehicle owner is determined as of the end of 1988 (USDHHS 1991). This approach ignores any bequest value of the vehicle. The individual's discounted remaining life years are calculated as

$$\text{Discounted Remaining Life Years}_j = \frac{1 - e^{-L_j r_2}}{r_2}$$

where L_j is the expected remaining life of the jth individual and r_2 is the discount rate over additional life years. Note that the discount rate on operating costs and the discount rate over remaining life years may or may not be the same value.

The discounted remaining life years of each individual j is weighted by the probability of a fatal accident in vehicle i to determine the expected life years of individual j lost as a result of owning vehicle i.

$$\text{Exp. Life Yrs Lost}_{ij} = Pr(\text{Fatality})_i * \text{Disc. Remaining Life Yrs}_j.$$

Moore and Viscusi called this value the quantity-adjusted life years for each individual.

The revised formulations for the life cycle variables are substituted into the hedonic formulation for the operating cost and safety attributes. (For varrable definitions, see the following sections.) The discount rates, r_1 and r_2, enter the price equation in a nonlinear form, requiring that the model be solved by a nonlinear optimization method.

Given the alterations incorporating life cycle concerns in the operating cost and safety variables, the equilibrium hedonic price locus can now be specified as

$$P_{(\text{auto})i} = \beta_0 + \sum_m \beta_m \left[\frac{1 - e^{-r_2 L_i}}{r_2} \text{RISK}_{mi} \right]$$

$$+ \sum_n \beta_n \left[\frac{1 - e^{r_1 T_i}}{r_1} \text{OPERATING COST}_{ni} \right] + \sum_k \beta_k A_{ki} + e_i ,$$

where m is an index over safety variables, n is an index over operating cost variables, and k is an index over other non-life cycle attributes. This life cycle specification of the hedonic price locus will be empirically estimated in section III.

In the economic literature using hedonic methods to examine empirical data from goods markets like housing and automobiles, a number of methodological issues arise repeatedly. Some issues arise in all applications of hedonic models, for example, model specification, multicollinearity, functional form, and the use of proxies for unobservable variables. Other issues are unique to automobile markets. The treatment of these issues in prior research and the relevance to the formulation of this model are reviewed in the following sections.

D. *Lessons from Prior Hedonic Automobile Studies*

There is a long history of automobile market data used in hedonic applications beginning with Court (1939). His model was originally developed to more accurately estimate automobile price indices. Since he first utilized such models, numerous authors have discussed refinements in the econometric models used to derive price indices (e.g. Triplett 1969, 1986, Griliches 1961, Ohta & Griliches 1976, and Cowling & Cubbin 1972 for the British auto market). These models are relevant in the present context for their lessons related to model specification.

A second set of studies have used hedonic models of the automobile market to estimate willingness-to-pay measures for automobile attributes, including fuel economy, and in one case for vehicle safety (Goodman 1983, Hogarty 1975, Atkinson & Halvorsen 1984, 1990, Ohta & Griliches 1986). In many of these efforts, the sign and significance of the willingness-to-pay parameter for fuel economy were not as predicted based on expectations about consumer responses to economic incentives. Incorporating the lessons drawn from these studies and using a new data set yields the estimates presented below; though, some questions as to the validity of the willingness-to-pay for fuel economy improvements remain.

E. ***Overview of the Empirical Data Set***

The data used in the estimates which follow provide a particular advantage over the studies cited above in that these data reflect actual consumer automobile holdings; hence, they embody real marketplace tradeoffs between attributes made by individual consumers. The data sets used in previous studies were developed from listings of manufacturers' offerings or used car source books. No actual consumer choices were reflected in these data sets.

This study incorporates the actual vehicle holdings of respondents to the 1988 Residential Transportation Energy Consumption Survey (RTECS) conducted by the U.S. Department of Energy (DOE).[7] In 1988, DOE collected transportation-related energy data from a cross-section of 2,986 sampled households. The survey included questions on vehicle holdings, usage, vehicle characteristics, and the socioeconomic status of the respondents. Additional vehicle attribute data have been collected from industry sources to supplement the RTECS data. A detailed description of the RTECS data set, the RTECS data elements, and the data collected by the author are contained in the appendix. A brief description of the variables used in the empirical estimates is provided in Table 1, and selected summary statistics are presented in Tables 2 and 3.

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[7] For a description of the survey, see U.S. DOE, 1990.

Table 1: Variable Descriptions

Price: Vehicle price as of end of year 1988. New price for model year 1988 vehicles, used car market prices for older cars.

Mortality Rate: Number of fatalities occurring in that make/model/year vehicle divided by number of vehicles on the road.

Injury Rating: Vehicle injury rating measured relative to the rating for the median vehicle. Median rating equals one hundred, and lower values are safer cars.

Operating Cost: Vehicle operating costs measured in dollars of fuel expenditure per year. Calculated as gas price divided by miles per gallon times average miles travelled.

Operating Cost : Weight: Vehicle operating cost per unit of vehicle weight.

Power: The horsepower to weight ratio as a measure of vehicle power/acceleration.

Cargo Capacity: Vehicle cargo space in cubic feet.

Maintenance Rating: A discrete variable coded as one if the Consumer Reports maintenance rating is two or higher, and coded as zero if the maintenance rating is below two.

Luxury-Sport: A discrete variable coded as one if the vehicle is classified as a luxury or sport vehicle.

Automatic Transmission: A discrete variable coded as one if the vehicle has an automatic transmission.

Twoseat: A discrete variable coded as one if the vehicle is a two seat model.

Convertible: A discrete variable coded as one for convertibles.

Wagon: A discrete variable coded as one for station wagons.

Diesel: A discrete variable coded as one for diesel models.

Table 1: Variable Descriptions (continued)

AMC, Ford, GM, Chrysler, Germany, Japan, Other: Discrete variables coded as one for the manufacturer of domestic vehicles and for foreign vehicles, coded as one for the nation of origin. **YearXX:** Discrete variables coded as one for the vehicle model year. **SizeX:** Discrete variables coded as one for the appropriate size category. Four size categories are included, from **Size1**, smallest, to **Size4**, largest. **Resale Value Retained:** The percentage of original sales value retained, as of end of year 1988.

Table 2: Means*, Standard Deviations, and Anticipated Signs of Selected Variables with Respect to Price

VARIABLE	MEAN	STANDARD DEVIATION	ANTICIPATED SIGN
Mortality Rate (x 1000)	0.1962	0.0957	(-)
Injury Rating	100.93	23.61	(-)
Operating Cost	563.65	144.08	(-)
Power	0.04	0.01	(+)
Cargo Capacity	15.18	5.57	(+)
Weight	2724.65	568.20	(-)
Maintenance Rating	0.91	0.28	(+)
Luxury-Sport	0.18	0.39	(+)
Automatic Trans.	0.76	0.43	(+)
Two Seat	0.02	0.14	(?)
Wagon	0.03	0.16	(?)
Convertible	0.01	0.06	(?)
Diesel	0.01	0.10	(?)
Resale Value+	57.59	16.77	(+)

* Means weighted by RTECS population sampling statistics.

\+ Excluding 1988 model year new cars.

Table 3: Mean* Values of Selected Attributes By Market Segment

MARKET SEGMENT	NUMBER OF OBS.	MORT. RISK (x1000)	INJURY RATING	OPERATING COST ($/YEAR)	CARGO SPACE (ft^3)	WEIGHT
BASE DATA SET+	1,775	0.193	100.6	545.1	15.2	2723
SIZE1	489	0.210	120.9	420.2	12.8	2077
SIZE2	422	0.208	106.7	507.7	14.5	2446
SIZE3	525	0.198	94.9	597.7	15.5	2946
SIZE4	339	0.144	74.1	680.9	19.0	3602
1988 NEW MODELS	257	0.218	103.4	690.6	15.0	2737

* Means weighted by RTECS population sampling statistics.

\+ Excluding 1988 model year new cars.

Because the data set contains information on the actual holdings of households, it is hoped that the willingness-to-pay values; for fuel economy will be more reliable. Each vehicle represents the actual tradeoffs among attributes made by some consumer in the marketplace. A wider selection of alternative vehicle models are included in this data set because many models are available equipped with a variety of optional engine types; hence, a named model may appear repeatedly in this data set with different attributes. Most previous studies included only one observation for a standardized version of each vehicle model.

Another unique aspect of this study is that the data reflect actual automobile holdings at a specific point in time, providing a snapshot of consumer behavior. Each vehicle's market price will reflect the opportunity cost of owning that specific vehicle. The implicit attribute values derived from households' vehicle holdings will provide insight into the tradeoffs in their vehicle stock, rather than just for new car purchases. Hence policies which may affect a household's vehicle stock as well as their new car choices can be examined.

F. *Model Specification*

Previous researchers have discovered that model specification is the greatest difficulty associated with hedonic automobile models. Closely linked to model specification is the difficulty of multicollinearity among explanatory variables. Underspecification will lead to biased regression coefficients, but as additional explanatory attributes are added to the model to improve its specification, a higher likelihood of multicollinearity may occur. Because several vehicle attributes are closely related linearly, for example, different vehicle size parameters, adding more variables may create multicollinearity. With collinear explanatory variables, the significance of the estimated coefficients may be reduced, but perhaps more important, the coefficients may become difficult to interpret. Several authors have reported coefficient instability related to multicollinearity.

A particular difficulty is introduced in the automobile market because of the relationship of vehicle weight to other attributes of interest. In his early study, Court recognized that "car weight *per* se is undesirable and in a complete analysis would have a negative net regression."[8]

Vehicle weight is an important vehicle design characteristic because of its physical contribution to several different aspects of vehicle performance. Holding all else equal, heavier cars are typically safer for occupants of those cars in the event of an accident. Similarly, a heavier vehicle will have higher operating costs per mile traveled.

[8]Court. *op.cit*. p. 113.

Because vehicles can be considered a bundle of attributes, all other factors are not held equal in a vehicle. Vehicle characteristics that alter weight may affect several different attributes of interest, and weight is only one design characteristic determining outcomes like safety and operating cost. Changes in other design features while holding weight constant, may alter safety or fuel economy. Though correlated with safety and fuel economy, weight is an imperfect proxy for these attributes.

Triplett (1969) paid particular attention to vehicle weight because of the correlation between weight and other attributes and because weight served as a proxy for other variables in his model. He used a sales-weighted collection of autos from 1960 through 1965 in a regression of price on vehicle weight and two dummy variables, a proxy for prestige vehicles, and a dummy variable for compact cars. He found that greater than 90 percent of price variability could be explained.' His more fully specified model added no further explanatory power.

'While Triplett observed that weight is not a desirable attribute of a vehicle, he incorporated weight in his model specification as a proxy for other characteristics. In the truncated model, he speculated that weight could have represented a number of desirable vehicle characteristics, such

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[9]In test regressions using 1988 new cars, a regression of vehicle weight alone on vehicle price has an adjusted R-square equal to approximately 0.65.

as the size or capacity of the vehicle, its durability, or its insulation against sound or vibration.

Griliches (1961) raised another difficulty associated with these models, especially those including weight as an explanatory variable. He noted that the correlation coefficients between several of his right-hand-side variables, including weight, length, and horsepower, fell in the range between 0.73 and 0.92. Such highly correlated explanatory variables led to coefficient instability across several different model specifications. When such high correlation is evident, he stressed that attributes should be included only if some independent variation among the variables could be shown and if the number of observations was large.

Models incorporating vehicle weight as an attribute variable face another difficulty raised by Triplett, use of proxy variables for unmeasured attributes. Triplett (1986) used weight as a measure of size and durability, but he pointed out that proxy variables must satisfy two criteria if they are to be meaningful. They must closely represent the unmeasured characteristic of interest, and the relationship between the proxy variable and the true characteristic must be stable over time. He also pointed out that the researcher can never be sure if shifts in this relationship do occur.

Following the lessons of these prior studies, the model below is specified as completely as possible while attempting to reduce the degree of collinearity among the attributes of interest. The explanatory variables included in the model have been chosen based on their relevance to consumers' decision-making. Weight is not included as a stand alone attribute, but is entered as an interaction term where appropriate. When the data allow, explicit attribute measures are used rather than proxy variables.

Safety, fuel economy, power, reliability, and durability are the most important attribute variables proposed to explain consumer holdings. After reviewing the economics literature related to vehicle choice and the available marketing information, these are the attributes deemed by the author as most important for consumer decision-making. Other important variables include physical characteristics, vehicle size, manufacturer/nation of origin, and vehicle age. In most prior studies, a measure of vehicle safety has been an important missing element.[10] Several studies incorporated vehicle weight as a proxy for safety, raising the complications outlined above.

The most important potentially missing variable in this model is a measure of vehicle styling. Hoffer and Reilly (1984) found that styling and styling changes were important factors underlying automobile demand. While several other

"Only Atkinson and Halvorsen (1990) include a measure of vehicle safety. Fuel economy is not included in their model as an explanatory variable, precluding an examination of the tradeoffs between fuel economy and safety.

variables which embody elements of vehicle styling are included, such as dummy variables for luxury and sport vehicles and vehicle size categories, no true measure of the value of styling will be generated.

Another variable commonly included in similar models but not incorporated here is vehicle handling. The only available measure of handling, the turning radius, proved to be too highly correlated with other characteristics to merit inclusion. Other attributes which have been used in hedonic automobile studies include slalom time as a measure of vehicle handling, noise and vibration insulation, leg room, ease of entry and exit, interior space, number of passengers seated comfortably, braking distance, and a variety of measures of vehicle size. These measures are not included here for a variety of reasons, especially, comprehensive data availability and multicollinearity concerns. Some degree of specification bias may be introduced as a result of excluded variables.

1. Variable Measurement Issues

As this research is based upon an original data set, many data issues arose concerning which variables to include in the data set, from what sources, and how best to measure the variables. A number of the most important issues are discussed below.

Vehicle Transactions Prices: Because the hedonic price locus represents equilibrium transactions prices of different attribute bundles, an empirical analysis should ideally incorporate actual automobile marketplace transactions prices. Such transactions prices were not available for newly purchased vehicles in the data set, so manufacturers' suggested retail prices are used as an alternative. Ohta and Griliches (1986) have pointed out that these prices are set by manufacturers and may not reflect market conditions.

In a study conducted using market data from 1974-1980 model year vehicles, Crafton and Hoffer (1981) investigated the relationship between actual vehicle transactions prices and the manufacturers' suggested sales price. Transactions prices were found to be related to vehicle inventory levels, manufacturer rebates to both dealers and consumers, and the degree of advertising by a'dealership. Though these results suggest that transactions prices in the new auto market respond to market conditions, they also demonstrate the limitations of manufacturers' suggested retail prices as proxies for new car sales prices.

A superior price measure is available for used vehicles. Prices for used cars from the Automobile Red Book, which incorporates data reported on actual transactions, should more accurately mirror market transactions prices.

Vehicle Safetv Measures: Vehicle safety is incorporated into the model with two separate measures. The first is the vehicle mortality rate measured by the ratio of the number of fatalities occurring in each make/model/year vehicle to the number of those vehicles on the road. Vehicle mortality rates were calculated based on information from the U.S. Department of Transportation's Fatal Accident Reporting System (FARS) for calendar year 1989. For each make/model/year vehicle, the mortality rate was calculated as follows,.

$$\text{MORTALITY RATE} = \frac{\text{TOTAL FATALITIES FOR 1989}}{\text{NUMBER MANUFACTURED * ON ROAD FACTOR}}$$

where the on-road factor accounts for the difference in the total number of that make/model/year vehicle manufactured and the number on the road in calendar year 1989. See the appendix for a more detailed discussion.

The second safety measure is based on the relative number of personal injury claims filed for each vehicle model normalized by the total insurance exposure written by insurance firms for that model. This measure can be loosely interpreted to represent the likelihood of injury resulting from a given accident in a specific vehicle. See the appendix for a more complete description of the variable. The sign on the coefficients of the two risk variables should be negative, as less safe cars (higher value of the variables in each case) are expected to have lower prices when holding all other attributes constant.

By using two measures of risk, it is intended that one will provide willingness-to-pay values for avoidance of fatal risks, while the other provides estimates for nonfatal injuries. The two variables may however introduce some double-counting as some of the personal injury claims compiled in the second safety measure may include claims associated with vehicle fatalities. Regression results will therefore be presented for models with only the mortality rate included as well as models with both variables.

It is anticipated that dropping injury from the formulation should raise the influence of mortality on vehicle price because the mortality variable will pick up some of the influence of the injury rating. If double-counting is a severe problem in the measurement of the two variables, the influence of both could be attenuated. When eliminating the double-counting in the regression with mortality alone, the influence of mortality on price would be greater as well.

Simply measuring vehicle mortality risk by the mortality rate of each vehicle is likely to result in biased regression coefficients. How safe any vehicle is depends upon the design and materials incorporated in the vehicle. Vehicle accident rates, however, also depend upon how safely the vehicle is driven. Hence measures of mortality risk are a composite of vehicle and driver characteristics. Vehicle and driver characteristics may not be independent because certain vehicles are more likely to be owned by those with particular demographic characteristics (e.g. households with children may own safer vehicles), and because as Peltzman (1975) first recognized, driving behavior may respond to vehicle safety characteristics. Safer cars may be driven "more intensively," that is faster and more recklessly because improved safety lowers the price (i.e. the likelihood/severity) of injury associated with driving intensity.

An ideal risk measure would relate fatalities strictly to the structural characteristics of each vehicle exclusive of driver characteristics. Of course, **no** such comprehensive measure exists. To account **partially** for the joint determination of mortality risk due to both automobile and driver characteristics in the FARS data set, a number of variables are included in the model which account for nonvehicle-specific determinants of mortality risk. This approach is similar to that of Atkinson and Halvorsen who also used mortality data derived from the FARS data base (Atkinson & Halvorsen 1990). These variables measure the proportion of fatalities in each make/model/year vehicle for which the specific characteristic applies. The variables are listed in Table 4. They include the proportion of young drivers and that of older drivers, proportion of accidents occurring late at night, proportion of one car accidents, proportion of

Table 4: Definitions of Driver Behavioral Variables

Young Driver: Proportion of fatalities in this make/model/year vehicle in which the driver was younger than twenty-five years.
Older Driver: Proportion of fatalities in this make/model/year vehicle in which the driver was forty-five years or older.
Late Night: Proportion of fatalities in this make/model/year vehicle which occurred between the hours of midnight and six in the morning.
One Car Accident: Proportion of fatalities in this make/model/year vehicle in which only one vehicle was involved.
Seat Belts: Proportion of fatalities in this make/model/year vehicle in which the driver was wearing a seat belt.
Alcohol Involvement: Proportion of fatalities in this make/model/year vehicle in which the on-scene police officer reported alcohol involvement.
Male Driver: Proportion of fatalities in this make/model/year vehicle in which the driver was male.

alcohol-related accidents, proportion of drivers wearing seat belts, and the proportion of male drivers." These variables were chosen because they encompass many of the important risk factors for vehicle accidents, like driving experience and alcohol involvement, and because they incorporate measures of risk-related behavior, such as whether drivers wear seat belts.

<u>Vehicle Ooerating</u> <u>Cost</u>: The fuel efficiency of each vehicle is measured by annual vehicle operating costs, where the operating cost is determined by the gallon cost of gasoline divided by the miles per gallon of fuel times average annual vehicle miles,

$$\text{Operating cost} = \frac{\frac{\$}{\text{gallon}}}{\frac{\text{miles}}{\text{gallon}}} * \text{ave. miles driven} = \frac{\$}{\text{year}}.$$

The price of gasoline is determined by the household's regional location and the fuel type reported for that vehicle. Vehicle MPG is an estimate of actual in-use fuel efficiency based on an adjustment algorithm described in the appendix. Average

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[11]Several attempts were made to "cleanse" the mortality rate data of nonvehicle-specific content using a two-stage approach in which mortality was modelled as a function of both vehicle-specific and either driver-specific characteristics (from the FARS data) or owner-specific characteristics (from RTECS). In the second stage, mortality values were predicted from vehicle-specific mortality coefficients generated in the first stage. This approach proved unsuccessful at generating reasonable values for the predicted mortality rate. Several factors may explain these poor results. The vehicle characteristics used to explain mortality risk may have been underspecified leading to biased coefficients then used to create predicted mortality values. Secondly, vehicle fatality exposure models such as those described by Evans (1984) rely upon vehicle weight as the principle determinant of mortality risk. Generating predicted values based on vehicle weight may have reinforced the multicollinearity among explanatory variables when predicted values were substituted into the hedonic price equation.

vehicle miles are calculated from the subset of RTECS respondents with valid responses to the mileage survey."

If consumers behave rationally in their automobile holdings, then the coefficient of operating cost should be negative. Consider two identical vehicles which differ only in their fuel economy. The price of the vehicle with greater fuel economy, lower operating costs, will be higher than the comparable car because buyers will bid up the price of the more efficient vehicle. Indeed, if the market efficiently capitalizes life cycle costs into vehicle prices, the increase in price should exactly compensate for the discounted value of the fuel savings over the anticipated vehicle life. If the price increase is less than that amount, then additional demand should continue to bid up the price of the more fuel efficient vehicle. Similarly, if vehicle price adjusts by more than that amount, the price will fall as demand for the other vehicle rises. If there is incomplete capitalization, the price adjustment will only partially offset the change in operating expenditure. Nevertheless, as long as the capitalization rate is greater than zero, the coefficient on operating cost should be negative.

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[12]Fewer than 65 percent of RTECS respondents supplied valid mileage values. Mileage estimates for the remaining households were imputed for RTECS reporting using a multiple regression procedure. Comparing the reported mileage values with the imputed mileage values shows that the imputation consistently under estimated vehicle miles. No differences in demographic characteristics between the reporting households and the imputed households could be demonstrated by the author to account for the differences. The valid mileage results were used to calculate the average mileage for new 1988 model year vehicles and for pre-1988 vehicles in the household stock.

In several previous hedonic studies of automobiles, unanticipated signs on fuel economy resulted (Goodman 1983, Cowling and Cubbin 1972, Hogarty 1975). These and subsequent authors (e.g. Atkinson and Halvorsen 1984) have speculated that the unexpected sign on fuel economy resulted from multicollinearity among automobile attributes used as explanatory variables for vehicle price. In only one study, Hogarty, are correlation coefficients among the vehicle attributes presented. The correlation coefficients between fuel economy and comfort, durability, engine speed, maneuverability, and performance all fall in the range between 0.75 and 0.88. Some other variables, such as comfort, durability, and engine speed share correlation coefficients of 0.97 to 0.99. Given such a high degree of collinearity among vehicle attributes, model instability due to multicollinearity may very well be responsible for incorrect signs or insignificant variables.

The potentially most troublesome remaining source of multicollinearity in this data set is that between operating cost and safety as measured by personal injury claims, with a correlation coefficient of -0.5."

To control for the effect of weight on operating cost in estimating the effect of operating cost on price, a separate variable interacting operating cost and weight is included in

[13]The simple correlation between operating cost and weight equals 0.73 while that between the safety measure and weight is -0.71.

the hedonic specification. Many different design factors affect the fuel economy performance of a vehicle. Aerodynamics, inclusion of fuel consuming options, engine design, and vehicle weight all play a part. The relationship between fuel economy and weight is a result of the fundamental relationship that additional mechanical energy is required to overcome additional inertia, or weight. Holding all other design and performance factors equal, a heavier car will be less fuel efficient. But if weight could be held constant, other design factors would explain variations in fuel economy. To capture this connection, operating costs are included in the model as a stand alone variable and as an interaction term with weight. The former should pick up variability in fuel economy related to vehicle weight and other factors, while the latter should show the influence of variability in fuel economy across cars not due to variations in weight.

<u>Vehicle Power/Acceleration</u>: The power of each vehicle is measured by the horsepower to weight ratio. The horsepower to weight ratio should most accurately reflect vehicle acceleration because raw horsepower is adjusted for the amount of weight which must be overcome. Alternative measures of power which have been used in prior studies, include zero to sixty acceleration, horsepower, and this ratio. A measure of vehicle acceleration would have been desirable as acceleration is most readily interpretable by consumers, but comprehensive

acceleration data were not available. An added advantage associated with this measure is that the ratio is uncorrelated with other explanatory variables.

Vehicle Maintenance/Reliability: A vehicle reliability measure is drawn from Consumer Reports as explained in the appendix. The raw data collected for reliability provide an ordinal measure of reliability rather than a cardinal measure. Therefore, reliability is incorporated in the regressions as a dummy variable with a value of one for vehicles with a five year average reliability rating of two and above and a value of zero for a rating of less than two.[14]

Cargo Capacity: Vehicle cargo capacity is included as a measure of vehicle size. Consumers may choose between specific vehicles based on the convenience provided by cargo space."

Expected Vehicle Life: Vehicle life is based on the age at which 50 percent of vehicles for a particular model year are expected to be scrapped (MVMA various years). This measure is intended to represent a consumer's expectation upon purchase of a vehicle of its useful life. Data for recent years indicate

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[14] In some test regressions, a set of dummy variables representing five reliability gradations was used, but including the set of dummy variables in the model along with dummy variables for vehicle manufacturers clouded the explanatory power of the model suggesting that reliability and vehicle manufacturer are too closely linked for inclusion of both sets of variables.

[15] Several variables were considered as measures of vehicle roominess/size including shoulder room, vehicle width, vehicle length, cargo capacity, and various indices incorporating several variables. Though cargo capacity is a desirable attribute in and of itself, of the roominess variables considered, it also proved to be the least correlated with vehicle weight, fuel economy, and with other explanatory variables.

that after thirteen years, fifty percent of the vehicles of each model year are no longer on the road. Though data are not available differentiating expected vehicle life by the manufacturer or vehicle type, a durability measure based on the retained resale value of each vehicle is included as a control to capture some of the variability in expected vehicle life within each model year.

Durabilitv: Vehicle durability is incorporated by a proxy variable measuring the proportion of the original sale value of the vehicle retained as of the end of 1988. No true measure of vehicle durability which would vary from one vehicle make/model/year to another was available. Other proxies such as the manufacturer of a vehicle vary across manufacturers, but do not allow for'variability across vehicle make. In addition, such variables measure more than just vehicle durability. Though resale value retained is also an imperfect proxy for durability, it is presumed that vehicles with high retained resale values will have a longer iife than vehicles with a lower proportion of original value retained. Because the relationship between durability and retained resale value may not be stable over time, in some regressions, this measure was interacted with the vehicle model year to allow the coefficient values to vary from year to year.

2. The Optimal Transformation

One issue which has been raised by many authors since Court first used hedonic analysis for automobiles is the appropriate functional form or transformation. There are no theoretical underpinnings pointing to any particular form. Most researchers have relied on the empirical data to reveal an appropriate functional form. A linear Box-Cox transformation is used here to identify the optimal form of the model.[16]

Using the Box-Cox transformation, the general hedonic equation is written as

$$P_{(\text{auto})\,i}^{\theta} = \sum_k \beta_k A_{ik}^{\lambda} + e_i$$

where k is an index over variables, i an index over observations, and λ and θ are the transformation coefficients which are interpreted as follows,

$$P_{(\text{auto})\,i}^{\theta} = \frac{P_{(\text{auto})\,i}^{\theta} - 1}{\theta} \quad \text{for } \theta \neq 0, \text{ and}$$

$$A_{ik}^{\lambda} = \frac{A_{ik}^{\lambda} - 1}{\lambda} \quad \text{for } \lambda \neq 0.$$

[16] Cropper, Deck, and McConnell (1988) tested a variety of transformations to determine the best transformation method. They considered models which were both fully specified and inaccurately specified. The transformation used here follows their conclusion that when the model may be incompletely specified, the linear Box-Cox minimizes potential errors in the parameter estimates.

If the transformation coefficients equal one, the model is linear, but as the transformation coefficients approach zero, the model takes a logarithmic form,

$$\lim_{\theta \to 0} P_{(\text{auto})i}^{\theta} = \ln P_{(\text{auto})i}, \quad \lim_{\lambda \to 0} A_{ik}^{\lambda} = \ln A_{ik}.$$

A grid search for the values of λ and θ over a range of minus two to plus two for all continuous right-hand-side variables (discrete variables were not transformed) resulted in right-hand-side transformation parameters of from 0.44 to 0.50 depending upon the particular regression specification. A left-hand-side transformation parameter of zero, implying a logarithmic form was assumed. The regression results in the tables that follow show the coefficients for the transformed variables. Standard errors are calculated as recommended by Greene (1993) using the Hessian matrix of second derivatives to compute the estimated asymptotic covariance matrix.

Substituting for the life cycle variables, the formulation can be written more completely as

$$P_{(\text{auto})i}^{\theta} = \beta_0 + \beta_1 \left[\frac{1 - e^{-r_2 L_j}}{r_2} \text{MORT. RISK}_i \right]^{\lambda} + \beta_2 \left[\frac{1 - e^{-r_2 T_i}}{r_2} \text{INJURY}_i \right]^{\lambda}$$

$$+ \beta_3 \left[\frac{1 - e^{r_1 T_i}}{r_1} \text{OPERATING COST}_i \right]^{\lambda} + \beta_4 \left[\frac{1 - e^{-r_1 T_i}}{r_1} \frac{\text{OP. COST}}{\text{WEIGHT}}_i \right]^{\lambda}$$

$$+ \sum_k \beta_k A_{ki}^{\lambda} + e_i ,$$

where as before, λ is the right-hand side Box-Cox transformation parameter and θ is constrained to equal zero. The subscript i refers to vehicle-specific information, and the subscript j refers to automobile owner-specific information.

As discussed above, two measures of safety and two measures of fuel economy are included. The life cycle variables are specified using two different expected time frames. The fatality variable is specified over the expected remaining life of the vehicle owner. For vehicle safety (non-fatal) and vehicle operating costs, the relevant time frame is over the life of the vehicle, not the life of the individual. A fatal accident ends an individual's life and any future life years once and for all. An injury is by definition nonfatal, and the probability of an injury changes as an individual exchanges between vehicles. Hence, the expected vehicle life is adopted as the appropriate discounting time frame.

This model specification facilitates distinct estimation of the capitalization rate from the discount rate. The regression coefficients are interpreted as the change in price resulting from a one dollar change in discounted life cycle operating costs or life cycle safety risk. Hence the regression coefficients for the life cycle variables measure the rate at which changes in life cycle costs are incorporated into price, i.e. the capitalization rate. The discount rate, one component of the life cycle values, is distinctly estimated.

G. *The Value of* a *Statistical Life Derived in* the *Life Cycle Framework*

Though the foundation of the value of life literature is in the labor market, 'economists have exploited empirical data in other markets to generate value of life estimates. The market for automobiles offers a comparable model where the price of a vehicle is comparable to the wage and the fatality risk associated with the vehicle is comparable to the job risk.

The workplace encompasses a bundle of different amenities, including safety. The estimated contribution of each amenity to the wage differential is determined by estimating the hedonic wage locus just as the contribution of each attribute in the automobile bundle can be determined from the hedonic price locus. The estimated regression coefficients represent the marginal contribution of each independent variable to the wage. This is the compensation that a marginal employee is willing to pay (receive) to avoid (accept) an additional increment of amenity i, the marginal price of the amenity.

This hedonic wage model is the foundation of the value of life literature. By comparing the incremental mortality risk of different jobs in a hedonic framework, the equilibrium valuation for the incremental risk can be determined as the partial derivative of the wage with respect to the incremental mortality risk. This unit risk measure can then give rise to an equilibrium valuation of a statistical *life,* which is rather loosely termed "the value of life."

Using automobile data, Atkinson and Halvorsen (1990) performed just this sort of analysis with a sample of 112 new vehicles from the 1978 model year. They calculated the capital cost of the vehicle as the purchase price times the sum of the real rate of interest, the rate of depreciation, the cost of insurance, and the effective property tax rate on automobiles.,

Their model is estimated with a double-logarithmic, sales-weighted regression of vehicle capital cost on acceleration, a size variable, a measure of front seat comfort, and **a** measure of fatal accident rating for each model derived from the Fatal Accident Reporting System data base. In addition to these vehicle characteristics, Atkinson and Halvorsen include several variables to correct for endogeneity of the risk variable based on driver characteristics of those involved in fatal accidents reported by FARS. They control for the driver contribution to the risk measure by including the proportion of fatal accidents for each model that involved alcohol, male drivers, and drivers below the age of twenty-five.

Their estimated model shows **that** a one percent increase in the number of fatal accidents per thousand vehicles sold lowered the capital cost of the vehicle by 0.15 percent. When translated into the standard value of life metric, the implicit value for the sample as a whole is $3.4 million in 1986 dollars. The implicit value of life varies inversely with the safety rating of each vehicle. For the vehicles in the safest quartile, the implicit value of life is $6.6 million, while for the highest risk quartile, the implicit value of life is $0.77 million.

Using a related approach, the quantity-adjusted value of a statistical life can be estimated from the life cycle model presented above. These estimates are similar to those of Atkinson and Halvorsen in the incorporation of, fatality data drawn from the FARS data set in an hedonic context, but this model expands on their approach by using actual vehicle holdings of the general public, relying on a more fully specified model--including a measure of nonfatal as well as fatal risks--and by using the life cycle approach which Viscusi and Moore introduced in their labor market studies. Atkinson and Halvorsen included fuel economy in their estimates of vehicle capital cost. This procedure eliminated fuel economy from their attribute set, deemphasizing implicit tradeoffs between risk and fuel economy. In the vehicle holdings from the RTECS data set, fuel economy is negatively correlated with vehicle safety. Underspecification from excluding fuel economy may have biased Atkinson and Halvorsen's coefficient estimates.

The most significant extension of this model is that it is based in a life cycle framework. This approach recognizes that the adverse outcome of a fatal automobile accident is not simply death, but the lost life years of the individual. In a sense, death is a differentiated commodity, differing across individuals based upon the number of life years lost. Younger individuals suffer greater potential lost life years in the event of a fatal accident than older individuals, and they may have substantially different valuations for a lost year. Another aspect of this model is that the life cycle approach allows for discounting of future life years.

Recall that the life cycle hedonic model can be specified as follows,

$$P^{\theta}_{(\text{auto})i} = \beta_0 + \beta_1\left[\frac{1 - e^{-r_2 L_j}}{r_2}\text{MORT. RISK}_i\right]^{\lambda} + \beta_2\left[\frac{1 - e^{-r_2 T_i}}{r_2}\text{INJURY}_i\right]^{\lambda}$$

$$+ \beta_3\left[\frac{1 - e^{r_1 T_i}}{r_1}\text{OPERATING COST}_i\right]^{\lambda} + \beta_4\left[\frac{1 - e^{-r_1 T_i}}{r_1}\frac{\text{OP. COST}}{\text{WEIGHT}}_i\right]^{\lambda}$$

$$+ \sum_k \beta_k A_{ki}{}^{\lambda} + e_i \,,$$

The first term on the right-hand-side of the equation,

$$\frac{1 - e^{-r_2 L_j}}{r_2}\text{MORTALITY RISK}_i = \text{EXPECTED LOST LIFE YEARS}_{ji},$$

the expected lost life years of person *j* when owning vehicle *i*, is analogous to what Moore and Viscusi (1988) called the quantity-adjusted life years for the individual. It is composed of two parts, the discounted number of life years remaining for that individual based upon the individual's race, age, and gender, and the death risk of the individual's automobile holding, yielding the expected number of life years lost for the individual based upon their personal characteristics and their vehicle holding.

The statistical value of life estimated in this life cycle context is calculated by taking the partial derivative of vehicle price with respect to the mortality rate,

$$\frac{\partial PRICE}{\partial MORTALITY\ RATE} = \beta_1 ELYL^{\lambda-1} * \frac{\partial ELYL}{\partial MORTALITY\ RATE} * PRICE,$$

where ELYL stands for the expected lost years of life and the final multiplication by price is necessary because the model was estimated on the natural log of price. Empirical estimates of the value of a statistical life are presented in the next section.